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(12) **United States Patent**
Yasuda

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(45) **Date of Patent: Sep. 19, 2023**

(54) **IMAGE DISPLAY DEVICE, IMAGE DISPLAY SYSTEM, IMAGE DISPLAY METHOD, AND COMPUTER PROGRAM FOR PROVIDING A LOW-LUMINANCE GRAYSCALE STANDARD DISPLAY FUNCTION (GSDF) DISPLAY**

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G09G 5/10 (2006.01)

(52) **U.S. Cl.**
CPC ***G09G 5/10*** (2013.01); *G09G 2360/16* (2013.01); *G09G 2380/08* (2013.01)

(58) **Field of Classification Search**
CPC .. G09G 5/10; G09G 2360/16; G09G 2380/08; G09G 2320/0271;
(Continued)

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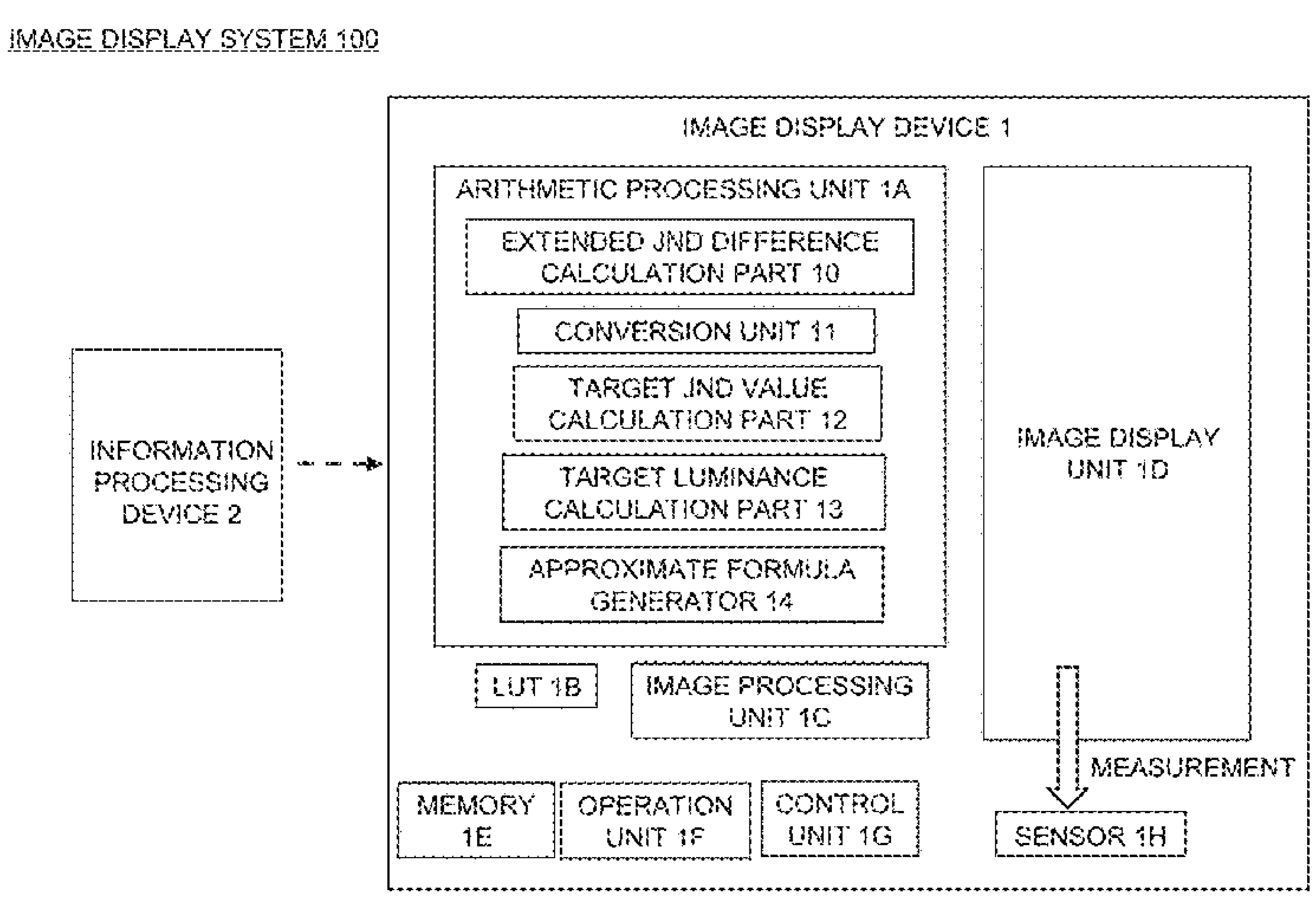
(57) **ABSTRACT**

An image display device, image display system, image display method and computer program which are configured so that not only the gradation characteristic at the luminance over 0.05 (cd/m2) but also the gradation characteristic at the luminance less than 0.05 (cd/m2) satisfies the DICOM. The image display device includes an image display unit; and an image processing unit. The image processing unit is configured to display the image data on the image display unit based on first and second gradation characteristics, a luminance of the first gradation characteristic is 0.05 (cd/m2) or more, a luminance of the second gradation characteristic is less than 0.05 (cd/m2), the first gradation characteristic complies with GSDF (Grayscale Standard Display Function) gradation characteristic of DICOM standard, and the first and second gradation characteristics are defined to satisfy a relationship between a JND value and a corresponding luminance.

14 Claims, 13 Drawing Sheets



(58) **Field of Classification Search**
CPC ... G09G 2320/0626; G09G 2320/0693; G09G 3/20; G09G 3/36; G09G 3/3208; G09G 2310/027; G09G 2320/0233
See application file for complete search history.

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FIG. 1

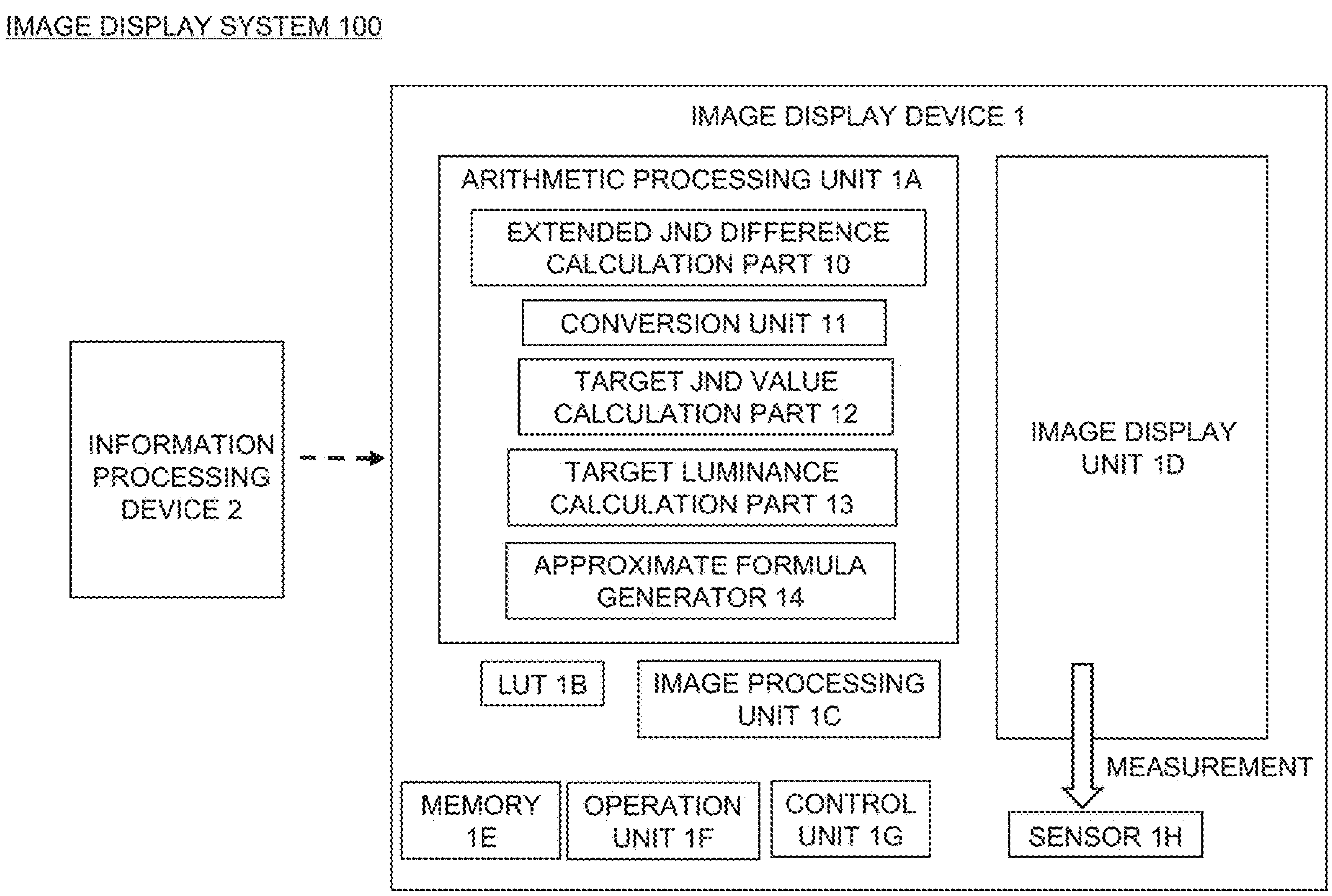
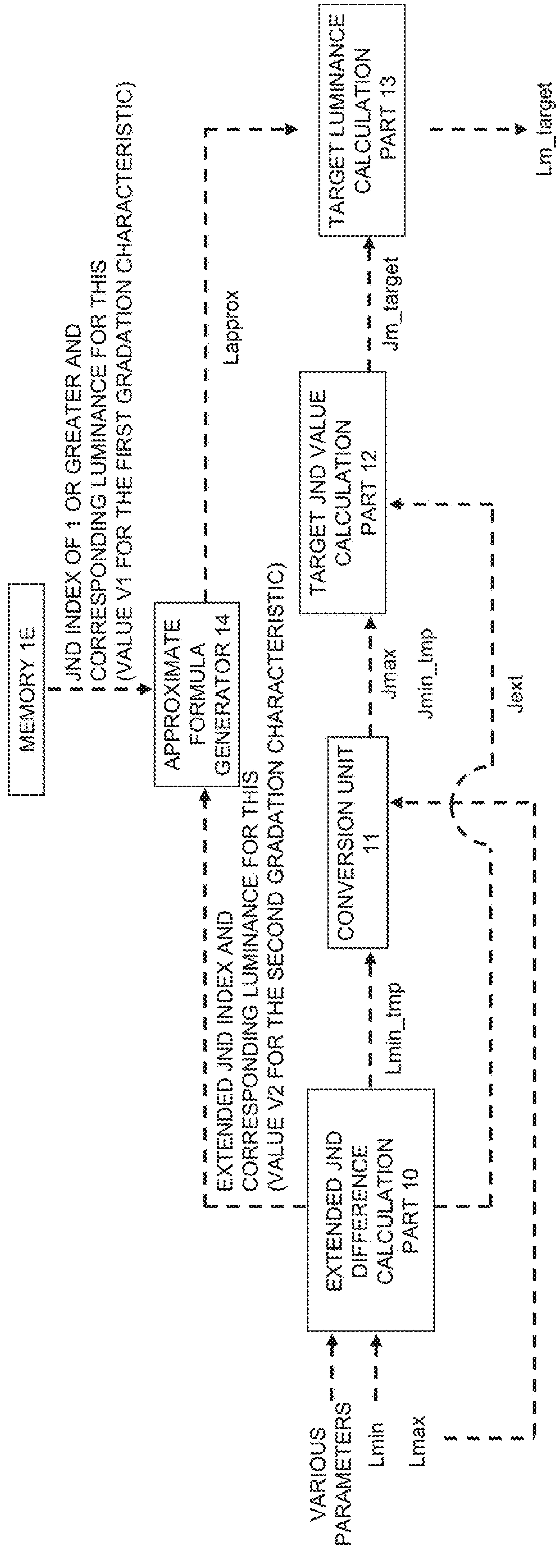


IMAGE DISPLAY SYSTEM 100
INFORMATION PROCESSING DEVICE 2
IMAGE DISPLAY DEVICE 1
ARITHMETIC PROCESSING UNIT 1A
EXTENDED JND DIFFERENCE CALCULATION PART 10
CONVERSION UNIT 11
TARGET JND VALUE CALCULATION PART 12
TARGET LUMINANCE CALCULATION PART 13
APPROXIMATE FORMULA GENERATOR 14
LUT 1B
IMAGE PROCESSING UNIT 1C
IMAGE DISPLAY UNIT 1D
MEASUREMENT
MEMORY 1E
OPERATION UNIT 1F
CONTROL UNIT 1G
SENSOR 1H

FIG. 2


MEMORY 1E
JND INDEX OF 1 OR GREATER AND CORRESPONDING LUMINANCE FOR THIS (VALUE V1 FOR THE FIRST GRADATION CHARACTERISTIC)
APPROXIMATE FORMULA GENERATOR 14
Lapprox
TARGET LUMINANCE CALCULATION PART 13
Lm_target
Jm_target
TARGET JND VALUE CALCULATION PART 12
Jmax
Jmin_tmp
Jext
CONVERSION UNIT 11
Lmin_tmp
EXTENDED JND INDEX AND CORRESPONDING LUMINANCE FOR THIS (VALUE V2 FOR THE SECOND GRADATION CHARACTERISTIC)
EXTENDED JND DIFFERENCE CALCULATION PART 10
VARIOUS PARAMETERS
Lmin
Lmax

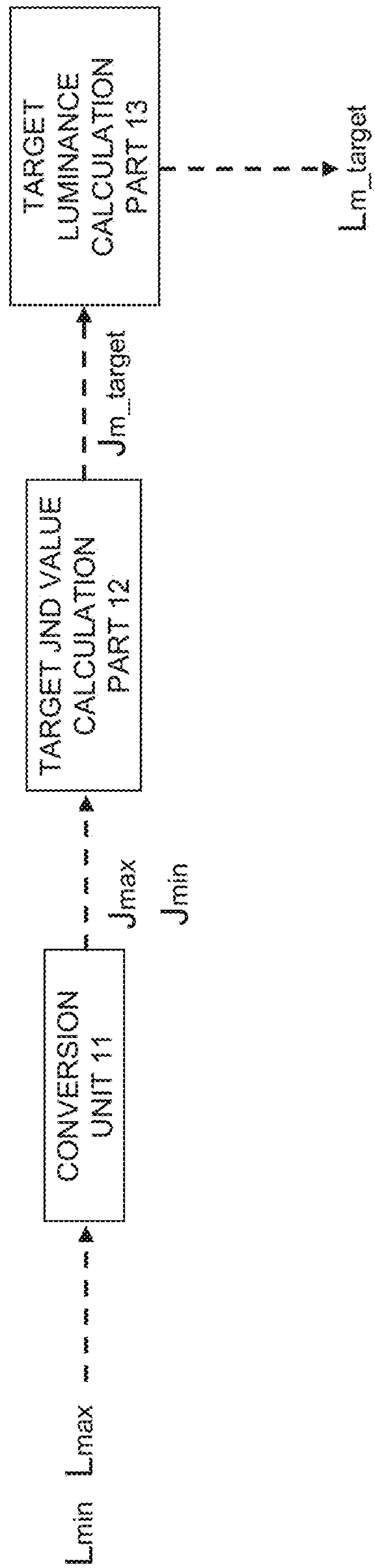

TARGET LUMINANCE CALCULATION PART 13
Lm_target
Jm_target
TARGET JND VALUE CALCULATION PART 12
Jmax
Jmin
CONVERSION UNIT 11
Lmin
Lmax

FIG. 3

FIG. 4

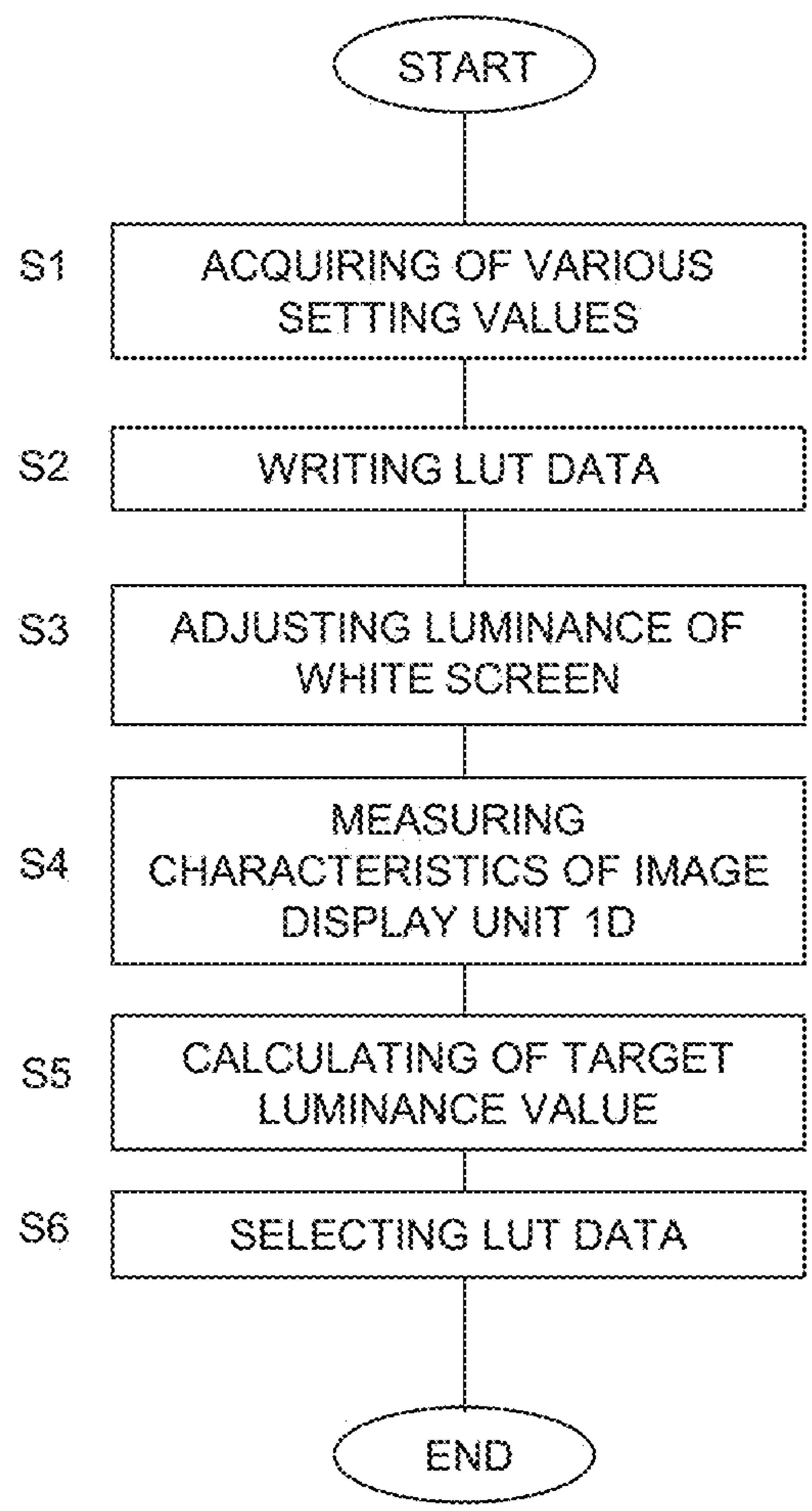

START
S1
ACQUIRING OF VARIOUS SETTING VALUES
S2
WRITING LUT DATA
S3
ADJUSTING LUMINANCE OF WHITE SCREEN
S4
MEASURING CHARACTERISTICS OF IMAGE DISPLAY UNIT 1D
S5
CALCULATING OF TARGET LUMINANCE VALUE
S6
SELECTING LUT DATA
END

FIG. 5

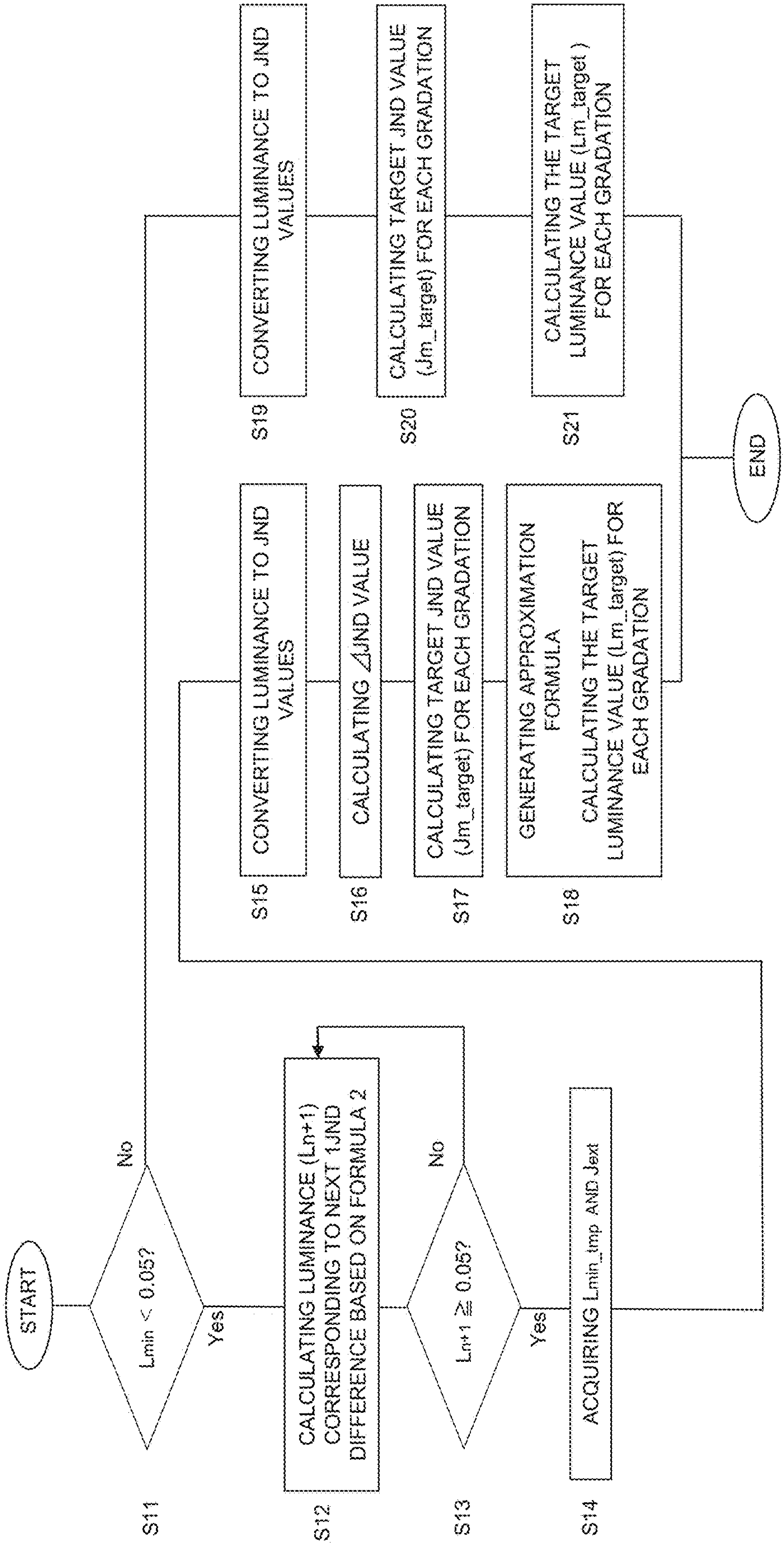

START
S11
L_{min} < 0.05?
No
Yes
S12
CALCULATING LUMINANCE (L_{n+1}) CORRESPONDING TO NEXT 1JND DIFFERENCE BASED ON FORMULA 2
S13
L_{n+1} ≧ 0.05?
No
Yes
S14
ACQUIRING L_{min_tmp} AND J_{ext}
S15
CONVERTING LUMINANCE TO JND VALUES
S16
CALCULATING ⊿JND VALUE
S17
CALCULATING TARGET JND VALUE (Jm_target) FOR EACH GRADATION
S18
GENERATING APPROXIMATION FORMULA
CALCULATING THE TARGET LUMINANCE VALUE (Lm_target) FOR EACH GRADATION
S19
CONVERTING LUMINANCE TO JND VALUES
S20
CALCULATING TARGET JND VALUE (Jm_target) FOR EACH GRADATION
S21
CALCULATING THE TARGET LUMINANCE VALUE (Lm_target) FOR EACH GRADATION
END

FIG. 6A

(FORMULA 1) CONTRAST SENSITIVITY FUNCTION

$$S(L) = \frac{q_1 \cdot M_{opt}(L)}{\sqrt{\frac{q_2}{d^2 L} + q_3}}$$

$q_1 = 0.1183034375$
$q_2 = 3.962774805 \cdot 10^{-5}$
$q_3 = 1.356243499 \cdot 10^{-7}$

$$M_{opt}(u) = e^{-\pi^2 \sigma^2 u^2} \qquad \sigma = \sqrt{\sigma_0^2 + (C_{sph} \cdot d^3)^2}$$

FIG. 6B

(FORMULA 2) FORMULA FOR CALCULATING LUMINANCE CORRESPONDING TO NEXT 1JND DIFFERENCE FROM THE CONTRAST SENSITIVITY FUNCTION

$$L_{n+1} = -1 * L_n \cdot \frac{1 + S(L_n)}{1 - S(L_n)}$$

FIG. 7A

(FORMULA 3) FORMULA FOR CONVERTING LUMINANCE TO JND VALUE

$$j(L) = A + B \cdot Log_{10}(L) + C \cdot (Log_{10}(L))^2 + D \cdot (Log_{10}(L))^3 + E \cdot (Log_{10}(L))^4 + F \cdot (Log_{10}(L))^5 + G \cdot (Log_{10}(L))^6 + H \cdot (Log_{10}(L))^7 + I \cdot (Log_{10}(L))^8$$

A = 71.498068	B = 94.593053	C = 41.912053
D = 9.8247004	E = 0.28175407	F = -1.1878455
G = -0.18014349	H = 0.14710899	I = - 0.017046845

FIG. 7B

(FORMULA 4) FORMULA FOR CONVERTING JND VALUE TO LUMINANCE

$$\log_{10} L(j) = \frac{a + c \cdot Ln(j) + e \cdot (Ln(j))^2 + g \cdot (Ln(j))^3 + m \cdot (Ln(j))^4}{1 + b \cdot Ln(j) + d \cdot (Ln(j))^2 + f \cdot (Ln(j))^3 + h \cdot (Ln(j))^4 + k \cdot (Ln(j))^5}$$

a = -1.3011877	b = -2.5840191E-2	c = 8.0242636E-2
d = -1.0320229E-1	e = 1.3646699E-1	f = 2.8745620E-2
g = -2.5468404E-2	h = -3.1978977E-3	k = 1.2992634E-4
m = 1.3635334E-3		

FIG. 8A

(FORMULA 5) FORMULA FOR CALCULATING ΔJND

$$\Delta JND = (J_{max} - J_{min\_tmp} + J_{ext}) / 255$$
$$= (810.49 - 1.62 + 19)$$
$$= 3.246$$

VALUE CORRESPONDING TO NUMBER OF GRADATIONS

ΔJND : EXTENDED JND DIFFERENCE
J_{max} : MAXIMUM JND VALUE
J_{min_tmp} : TEMPORARY MINIMUM JND VALUE
J_{ext} : EXTENDED JND DIFFERENCE

FIG. 8B

(FORMULA 6) FORMULA FOR CALCULATING TARGET JND VALUE (Jm_target) FOR EACH GRADATION

$$J_{m\_target} = J_{max} - \Delta JND \times (255 - m)$$

ΔJ_{m_target} : TARGET JND VALUE FOR EACH GRADATION
J_{max} : MAXIMUM JND VALUE

FIG. 8C

(FORMULA 7) FORMULA FOR CALCULATING TARGET JND VALUE (Jm_target) FOR EACH GRADATION

$$J_{m\_target} = (J_{max} - J_{min}) \times (255/m) + J_{min}$$

J_{max} : MAXIMUM JND VALUE
J_{min} : MINIMUM JND VALUE

FIG. 9

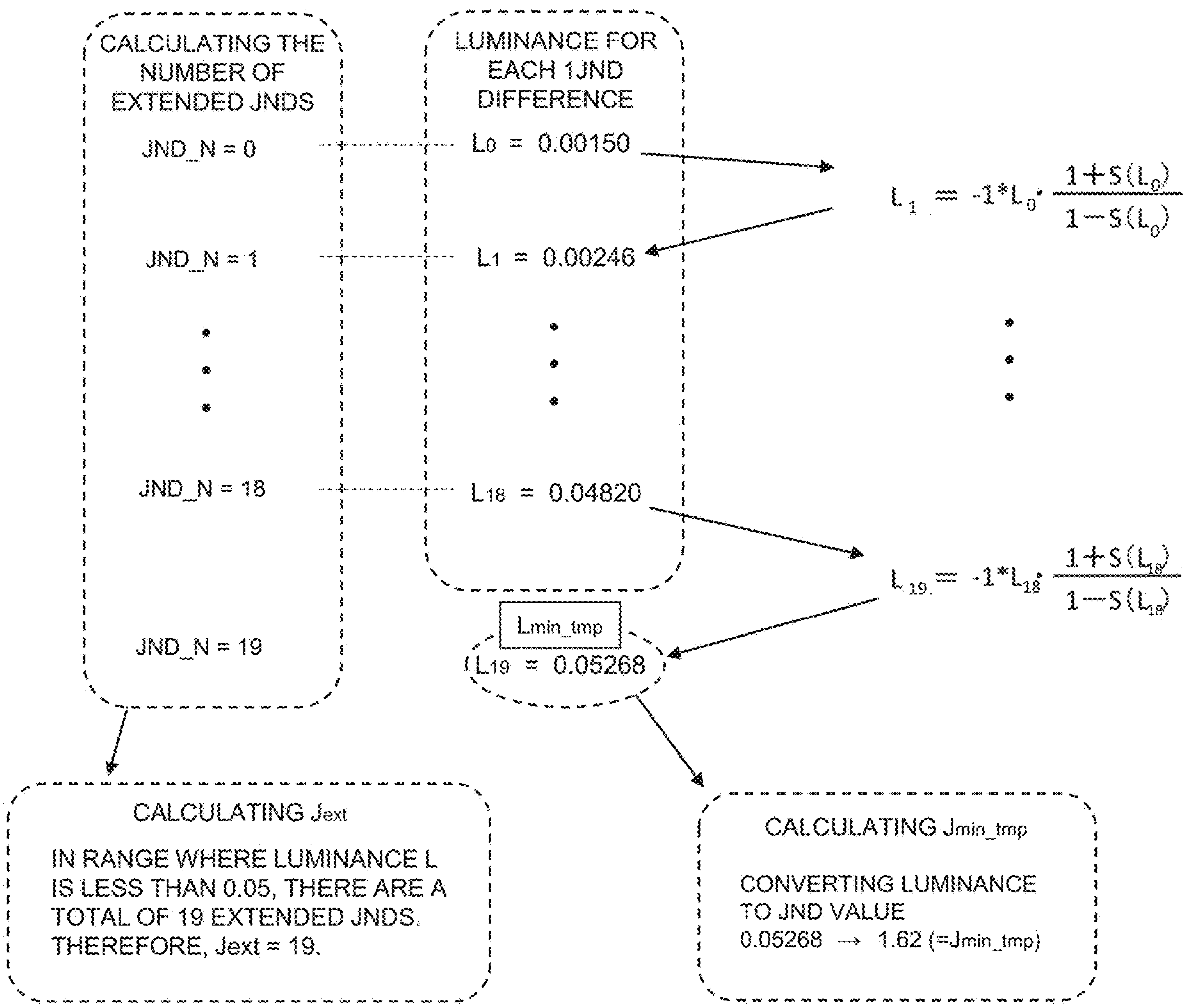

CALCULATING THE NUMBER OF EXTENDED JNDS
JND_N = 0
JND_N = 1
JND_N = 18
JND_N = 19
LUMINANCE FOR EACH 1JND DIFFERENCE
L0 = 0.00150
L1 = 0.00246
L18 = 0.04820
Lmin_tmp
L19 = 0.05268
$L_1 = -1*L_0 \cdot \frac{1+S(L_0)}{1-S(L_0)}$
$L_{19} = -1*L_{18} \cdot \frac{1+S(L_{18})}{1-S(L_{18})}$
CALCULATING Jext
IN RANGE WHERE LUMINANCE L IS LESS THAN 0.05, THERE ARE A TOTAL OF 19 EXTENDED JNDS. THEREFORE, Jext = 19.
CALCULATING Jmin_tmp
CONVERTING LUMINANCE TO JND VALUE
0.05268 → 1.62 (=Jmin_tmp)

FIG. 10

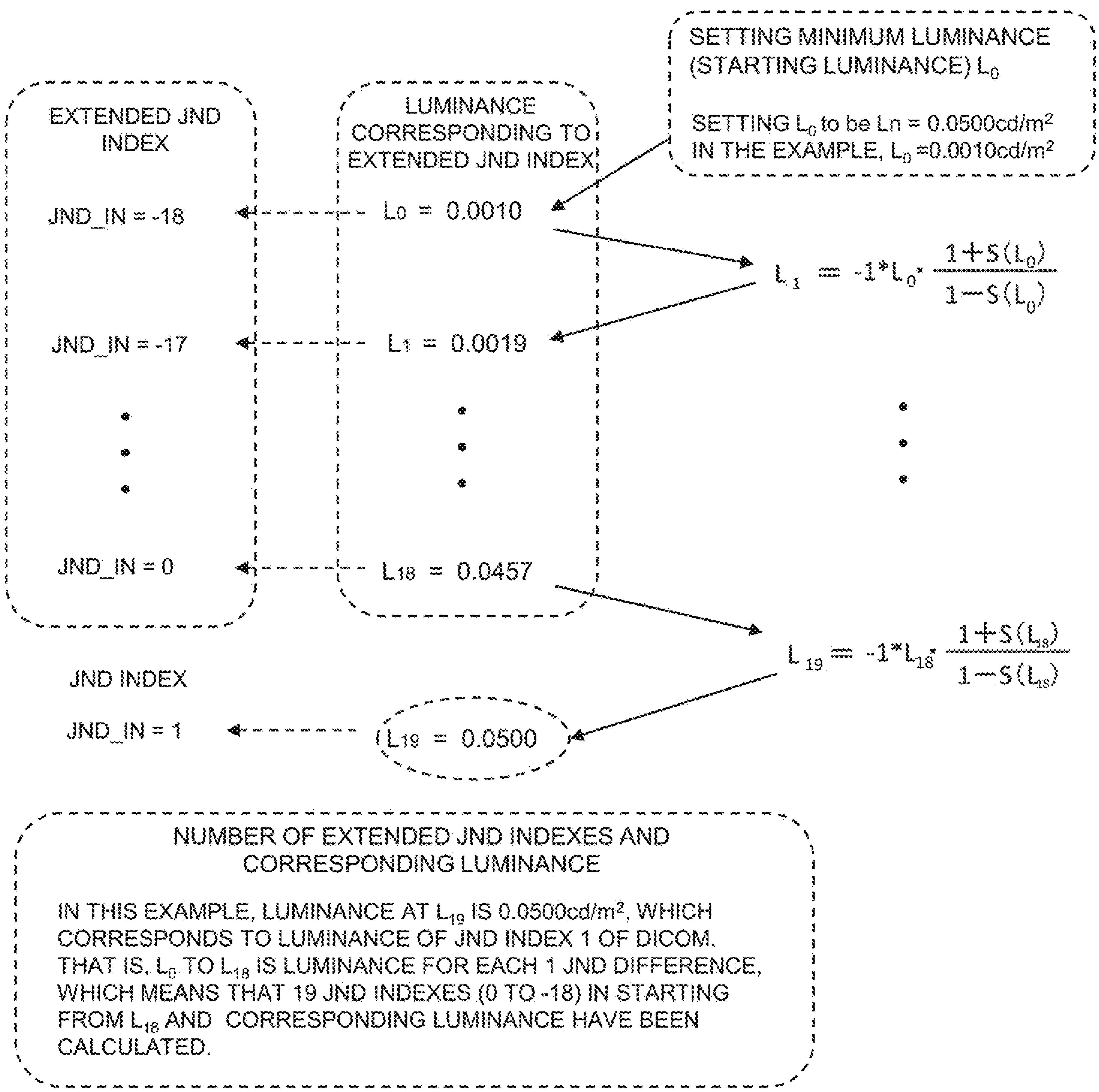
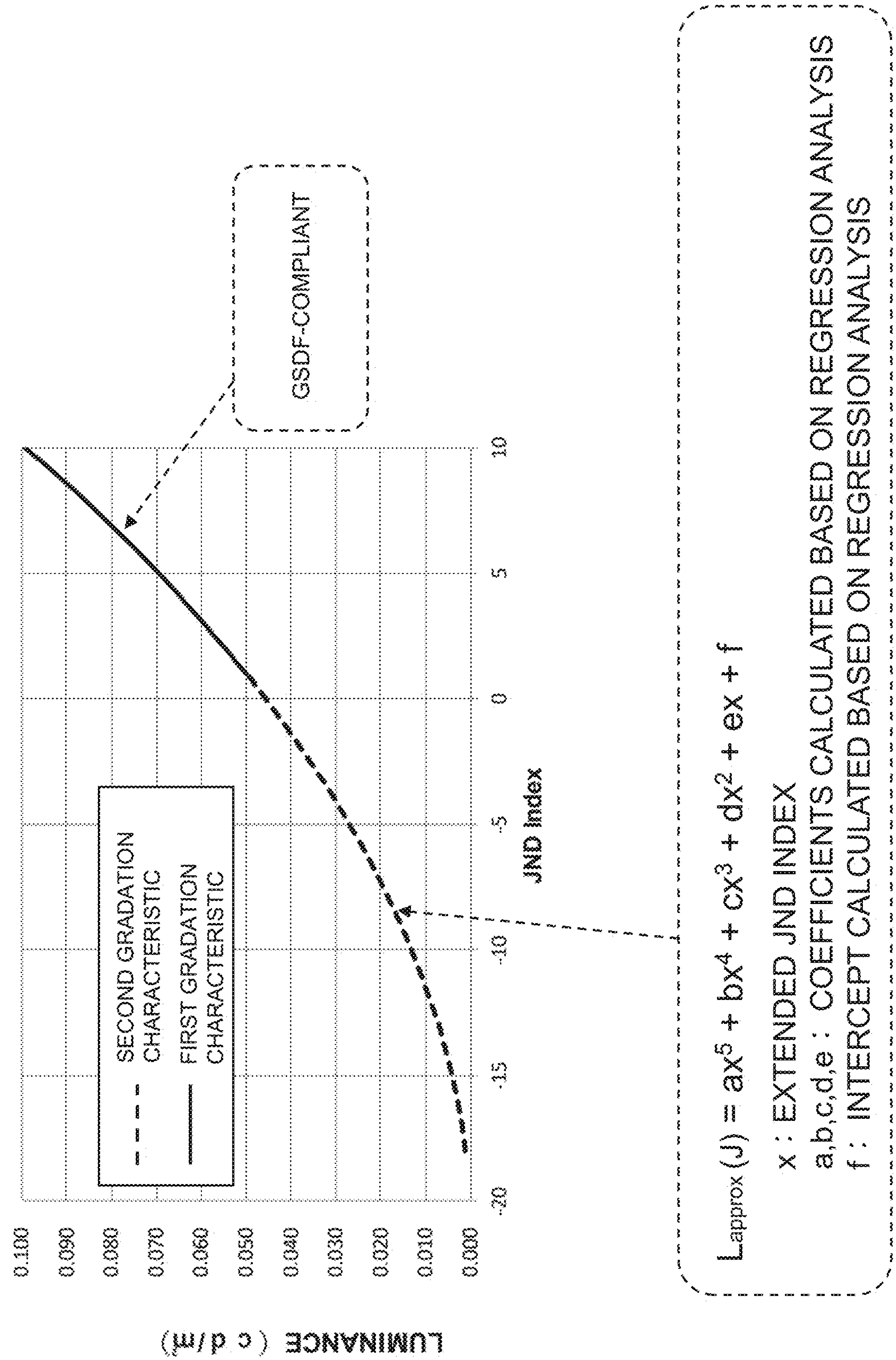

SETTING MINIMUM LUMINANCE (STARTING LUMINANCE) L_0
SETTING L_0 to be Ln = 0.0500cd/m^2 IN THE EXAMPLE, L_0 =0.0010cd/m^2
EXTENDED JND INDEX
LUMINANCE CORRESPONDING TO EXTENDED JND INDEX
JND_IN = -18
L_0 = 0.0010
$L_1 = -1 * L_0 * \frac{1+S(L_0)}{1-S(L_0)}$
JND_IN = -17
L_1 = 0.0019
JND_IN = 0
L_{18} = 0.0457
$L_{19} = -1 * L_{18} * \frac{1+S(L_{18})}{1-S(L_{18})}$
JND INDEX
JND_IN = 1
L_{19} = 0.0500
NUMBER OF EXTENDED JND INDEXES AND CORRESPONDING LUMINANCE
IN THIS EXAMPLE, LUMINANCE AT L_{19} IS 0.0500cd/m^2, WHICH CORRESPONDS TO LUMINANCE OF JND INDEX 1 OF DICOM. THAT IS, L_0 TO L_{18} IS LUMINANCE FOR EACH 1 JND DIFFERENCE, WHICH MEANS THAT 19 JND INDEXES (0 TO -18) IN STARTING FROM L_{18} AND CORRESPONDING LUMINANCE HAVE BEEN CALCULATED.

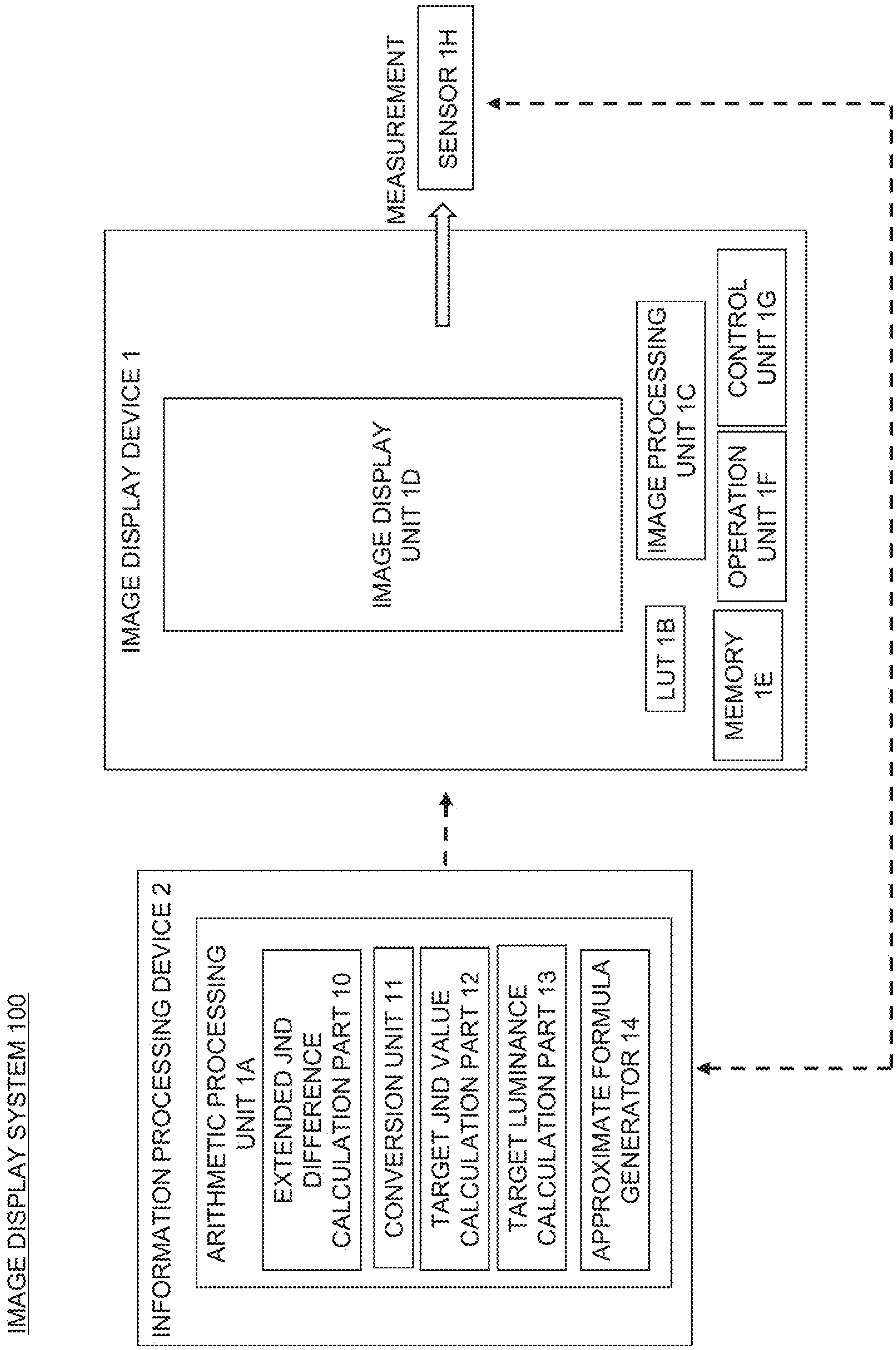
FIG. 11

TARGET JND VALUE CORRESPONDING TO EXTENDED JND INDEX

GRADATION	TARGET JND VALUE	TARGET LUMINANCE VALUE
0	-17.4	0.00153
1	-14.1	0.00536
2	-10.9	0.01120
3	-7.6	0.01904
4	-4.4	0.02893
5	-1.1	0.04091
6	2.1	0.05514
7	5.3	0.07142
8	8.6	0.09021
9	11.8	0.11133
10	15.1	0.13483
•	•	•
246	781.3	825.02255
247	784.5	842.88102
248	787.8	861.11661
249	791.0	879.73729
250	794.3	898.75119
251	797.5	918.16662
252	800.7	937.99208
253	804.0	958.23622
254	807.2	978.90791
255	810.5	1000.01618

FIG. 12


LUMINANCE (cd/m²)
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-20
-15
-10
-5
0
5
10
JND Index
SECOND GRADATION CHARACTERISTIC
FIRST GRADATION CHARACTERISTIC
GSDF-COMPLIANT
L approx (J) = ax5 + bx4 + cx3 + dx2 + ex + f
x : EXTENDED JND INDEX
a,b,c,d,e : COEFFICIENTS CALCULATED BASED ON REGRESSION ANALYSIS
f : INTERCEPT CALCULATED BASED ON REGRESSION ANALYSIS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INFORMATION PROCESSING DEVICE 2
ARITHMETIC PROCESSING UNIT 1A
EXTENDED JND DIFFERENCE CALCULATION PART 10
CONVERSION UNIT 11
TARGET JND VALUE CALCULATION PART 12
TARGET LUMINANCE CALCULATION PART 13
APPROXIMATE FORMULA GENERATOR 14
IMAGE DISPLAY DEVICE 1
IMAGE DISPLAY UNIT 1D
LUT 1B
MEMORY 1E
IMAGE PROCESSING UNIT 1C
OPERATION UNIT 1F
CONTROL UNIT 1G
MEASUREMENT SENSOR 1H

FIG. 13

IMAGE DISPLAY DEVICE, IMAGE DISPLAY SYSTEM, IMAGE DISPLAY METHOD, AND COMPUTER PROGRAM FOR PROVIDING A LOW-LUMINANCE GRAYSCALE STANDARD DISPLAY FUNCTION (GSDF) DISPLAY

TECHNICAL FIELD

The present invention relates to an image display device, an image display system, an image display method, and a computer program.

BACKGROUND

Improvements in image processing technology have made it possible to produce the image display devices that can display images with high contrast ratio. Such the image display device is capable of setting the gradation corresponding to the luminance of less than 0.05 (cd/m^2). Here, the gradation characteristic of the image display device for medical use is required to comply with the GSDF (Grayscale Standard Display Function) of the DICOM standard (hereinafter referred to as the DICOM). Therefore, an image display device that can display images of the gradation characteristic in compliance with the GSDF has been proposed (see, for example, patent literature 1). The GSDF of the DICOM is based on a theory called the Barten-Model.

The image display device described in patent literature 1 calculates the JND value corresponding to the maximum luminance and the JND value corresponding to the minimum luminance, and then calculates the target luminance for each gradation based on these JND values. In patent literature 1, the calculated target luminance shows the gradation characteristic in compliance with the GSDF. Here, the corresponding luminance corresponding to each JND index specified by the DICOM is 0.05 (cd/m^2) or more. Therefore, if the minimum luminance preset for the image display device is 0.05 (cd/m^2) or more, the image display device described in patent literature 1 can display images that comply with the GSDF.

PATENT LITERATURE

[Patent Literature 1] The publication of Japanese Patent No. 3974630

SUMMARY OF INVENTION

The JND Index (JND value) corresponding to the luminance less than 0.05 (cd/m^2) is not clearly indicated in the DICOM. Therefore, when the technology described in patent literature 1 is applied to the image display device that is capable of displaying images with high contrast ratio, if the minimum luminance preset for the image display device is less than 0.05 (cd/m^2), it is considered that the luminance of the low-gradation display image is outside the GSDF.

An object of the present invention is to provide the image display device, the image display system, the image display method and the computer program in which the gradation characteristics compatible with the GSDF are extended to a luminance range of less than 0.05 (cd/m^2).

The present invention provides an image display device for medical use configured to display image data comprising: an image display unit; and an image processing unit, wherein the image processing unit is configured to display the image data on the image display unit based on first and second gradation characteristics, a luminance of the first gradation characteristic is 0.05 (cd/m^2) or more, a luminance of the second gradation characteristic is less than 0.05 (cd/m^2), the first gradation characteristic complies with GSDF (Grayscale Standard Display Function) gradation characteristic of DICOM standard, and the first and second gradation characteristics are defined to satisfy a relationship between a JND value and a corresponding luminance.

The configuration of the present invention is configured to display image data on the image display unit based on the first and second gradation characteristics. Here, the first gradation characteristic (the gradation characteristic having the luminance of 0.05 (cd/m^2) or more) complies with the gradation characteristic of the GSDF of the DICOM standard and satisfies the relationship between the JND value (JND index) and the corresponding luminance corresponding to the JND value. The second gradation characteristic (the gradation characteristic having the luminance less than 0.05 (cd/m^2)) also satisfies the relationship between the JND value (JND index) and the corresponding luminance corresponding to the JND value. Therefore, the gradation characteristic of the invention, which is compatible with the GSDF, is extended to the luminance region of less than 0.05 (cd/m^2).

Various embodiments of the present invention are described below. Any of the embodiments described below can be combined with one another.

Preferably, the relationship of the second gradation characteristic corresponds to a relationship between a target JND value and a corresponding target luminance, the target luminance corresponds to the corresponding luminance, the target JND value is calculated based on a maximum JND value, an extended JND difference, a temporary minimum JND value, and the number of gradation, the maximum JND value corresponds to a maximum luminance of the image display unit, the temporary minimum JND value corresponds to a temporary minimum luminance, and the temporary minimum JND value is calculated from a minimum luminance using a predetermined relationship, the minimum luminance is less than 0.05 (cd/m^2), when the minimum luminance is given, the predetermined relationship is capable of recursively calculating a luminance corresponding to a JND value that is n (n≥1) larger than a minimum JND value corresponding to the minimum luminance, the temporary minimum luminance is a luminance that becomes larger than a predetermined luminance for the first time when a recursive calculation of each luminance using the predetermined relationship is repeated, and the extended JND difference corresponds to the number of luminance, which is used to calculate the temporary minimum luminance, smaller than the temporary minimum luminance.

Preferably, the image display device further comprises: an arithmetic processing unit, wherein the arithmetic processing unit includes an extended JND difference calculation part, a target JND value calculation part, and a target luminance calculation part, the extended JND difference calculation part calculates a temporary minimum luminance from a minimum luminance using a predetermined relationship and calculates an extended JND difference, when the minimum luminance is given, the predetermined relationship is capable of recursively calculating a luminance corresponding to a JND value that is n (n≥1) larger than a minimum JND value corresponding to the minimum luminance, the temporary minimum luminance is a luminance that becomes larger than a predetermined luminance for the first time when a recursive calculation of each luminance using the predetermined relationship is repeated, the minimum luminance is less than 0.05 (cd/m^2), the extended JND difference corresponds to the number of luminance, which is used to calculate the temporary minimum luminance, smaller than the temporary minimum luminance, the target JND value calculation part calculates a target JND value for each gradation based on a maximum JND value corresponding to a maximum luminance of the image display unit, the extended JND difference, a temporary minimum JND value corresponding to the temporary minimum luminance, and the number of gradation, the target luminance calculation part calculates a target luminance based on the target JND value, the target JND value corresponds to the JND value of the first and second gradation characteristics, and the target luminance corresponds to the corresponding luminance of the first and second gradation characteristics.

Preferably, the JND value is used in an arithmetic processing unit, the JND value for the first gradation characteristic is assigned a real number larger than or equal to 1, and the JND value for the second gradation characteristic is assigned a real number less than 1.

Preferably, a JND index is used in an arithmetic processing unit, the JND index for the first gradation characteristic is assigned an integer larger than or equal to 1, and the JND index for the second gradation characteristic is assigned an integer less than 1.

Preferably, the JND index for the second gradation characteristic is assigned a negative integer.

Another aspect of the present invention provides an image display system for medical use configured to display image data comprising: an image display unit; and an image processing unit, wherein the image processing unit is configured to display the image data on the image display unit based on first and second gradation characteristics, a luminance of the first gradation characteristic is 0.05 (cd/m^2) or more, a luminance of the second gradation characteristic is less than 0.05 (cd/m^2), the first gradation characteristic complies with GSDF (Grayscale Standard Display Function) gradation characteristic of DICOM standard, and the first and second gradation characteristics are defined to satisfy a relationship between a JND value and a corresponding luminance.

Preferably, the relationship of the second gradation characteristic corresponds to a relationship between a target JND value and a corresponding target luminance, the target luminance corresponds to the corresponding luminance, the target JND value is calculated based on a maximum JND value, an extended JND difference, a temporary minimum JND value, and the number of gradation, the maximum JND value corresponds to a maximum luminance of the image display unit, the temporary minimum JND value corresponds to a temporary minimum luminance, and the temporary minimum JND value is calculated from a minimum luminance using a predetermined relationship, the minimum luminance is less than 0.05 (cd/m^2), when the minimum luminance is given, the predetermined relationship is capable of recursively calculating a luminance corresponding to a JND value that is n (n≥1) larger than a minimum JND value corresponding to the minimum luminance, the temporary minimum luminance is a luminance that becomes larger than a predetermined luminance for the first time when a recursive calculation of each luminance using the predetermined relationship is repeated, and the extended JND difference corresponds to the number of luminance, which is used to calculate the temporary minimum luminance, smaller than the temporary minimum luminance.

Preferably, the image display system further comprises: an arithmetic processing unit, wherein the arithmetic processing unit includes an extended JND difference calculation part, a target JND value calculation part, and a target luminance calculation part, the extended JND difference calculation part calculates a temporary minimum luminance from a minimum luminance using a predetermined relationship and calculates an extended JND difference, when the minimum luminance is given, the predetermined relationship is capable of recursively calculating a luminance corresponding to a JND value that is n (n≥1) larger than a minimum JND value corresponding to the minimum luminance, the temporary minimum luminance is a luminance that becomes larger than a predetermined luminance for the first time when a recursive calculation of each luminance using the predetermined relationship is repeated, the minimum luminance is less than 0.05 (cd/m^2), the extended JND difference corresponds to the number of luminance, which is used to calculate the temporary minimum luminance, smaller than the temporary minimum luminance, the target JND value calculation part calculates a target JND value for each gradation based on a maximum JND value corresponding to a maximum luminance of the image display unit, the extended JND difference, a temporary minimum JND value corresponding to the temporary minimum luminance, and the number of gradation, the target luminance calculation part calculates a target luminance based on the target JND value, the target JND value corresponds to the JND value of the first and second gradation characteristics, and the target luminance corresponds to the corresponding luminance of the first and second gradation characteristics.

Preferably, the JND value is used in an arithmetic processing unit, the JND value for the first gradation characteristic is assigned a real number larger than or equal to 1, and the JND value for the second gradation characteristic is assigned a real number less than 1.

Preferably, a JND index is used in an arithmetic processing unit, the JND index for the first gradation characteristic is assigned an integer larger than or equal to 1, and the JND index for the second gradation characteristic is assigned an integer less than 1.

Preferably, the JND index for the second gradation characteristic is assigned a negative integer.

Another aspect of the present invention provides an image display method for medical use and displaying image data comprising: a display step of displaying the image data on an image display unit based on first and second gradation characteristics, wherein a luminance of the first gradation characteristic is 0.05 (cd/m^2) or more, a luminance of the second gradation characteristic is less than 0.05 (cd/m^2), the first gradation characteristic complies with GSDF (Grayscale Standard Display Function) gradation characteristic of DICOM standard, and the first and second gradation characteristics are defined to satisfy a relationship between a JND value and a corresponding luminance.

Another aspect of the present invention provides a computer program causing a computer to execute an image display method for medical use and displaying image data comprising: a display step of displaying the image data on an image display unit based on first and second gradation characteristics, wherein a luminance of the first gradation characteristic is 0.05 (cd/m^2) or more, a luminance of the second gradation characteristic is less than 0.05 (cd/m^2), the first gradation characteristic complies with GSDF (Grayscale Standard Display Function) gradation characteristic of DICOM standard, and the first and second gradation characteristics are defined to satisfy a relationship between a JND value and a corresponding luminance.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a functional block diagram of the image display system **100** having the image display device **1** according to the embodiment.

FIG. **2** is a description diagram of the data when the minimum luminance is less than 0.05 (cd/m^2).

FIG. **3** is a description diagram of the data when the minimum luminance is 0.05 (cd/m^2) or more.

FIG. **4** is a flowchart for mapping the LUT (Look Up Table) data to the target luminance obtained in the flowchart shown in FIG. **5**.

FIG. **5** is a detailed flowchart of step S**5** (a calculation step of the target luminance) of the flowchart shown in FIG. **4**.

FIG. **6**A shows a contrast sensitivity function derived from a Barten-Model.

FIG. **6**B shows a formula derived from the Barten-Model and which calculates the luminance corresponding to the next 1 JND difference from any the luminance.

FIG. **7**A is a formula for converting the luminance to the JND values, as specified by the DICOM.

FIG. **7**B is a formula for converting the JND value to the luminance, as specified by the DICOM.

FIG. **8**A is a formula used to calculate ΔJND.

FIG. **8**B is a formula used to calculate the target JND value when the minimum luminance is less than 0.05 (cd/m^2).

FIG. **8**C is a formula used to calculate the target JND value when the minimum luminance is 0.05 (cd/m^2) or larger.

FIG. **9** is a schematic diagram illustrating the calculation of the temporary minimum luminance from the minimum luminance using the contrast sensitivity function.

FIG. **10** is a schematic diagram illustrating the calculation of the extended JND index.

FIG. **11** is a table showing each gradation, the target JND value, and the target luminance.

FIG. **12** is a graph showing the first and second gradation characteristics.

FIG. **13** is a modification of the image display system **100** according to the embodiment.

DETAILED DESCRIPTION

Now, embodiments of the present invention will be described with reference to the drawings. Various features described in the embodiments below can be combined with each other.

1. Gradation Characteristic

1-1. Dicom Standard

The image display device for medical use should ensure consistency in image display to enable doctors and others to accurately read and diagnose images. For this reason, the image display device that complies with the DICOM standard (hereinafter referred to as DICOM), an international standard for digital images for medical use, has been proposed.

The DICOM specifies the GSDF (Grayscale Standard Display Function), a function that indicates the gradation characteristic. Human visual characteristics are non-linear with respect to brightness, but the GSDF is specified to be linear. Specifically, the GSDF is derived from the Barten-Model, which is based on human visual characteristics in image display.

In the DICOM, an index called the JND (Just-Noticeable Difference) Index is used. The starting point of the JND index is at a luminance of 0.05 (cd/m^2), which is defined as "1". After the JND indexes "2", the number of the JND index increases by 1 JND. 1 JND corresponds to the minimum luminance difference in the image recognizable by an average observer. In other words, since one step in the JND index is defined so as to attributed to the luminance difference which is the discrimination threshold, the corresponding luminance for the JND index is uniquely determined.

The JND index described here is specified as a positive integer. On the other hand, the JND value is the value assigned to each gradation and can be a value other than an integer. However, while the JND index and the JND value differ in whether or not they are integers, both the JND index and the JND value are essentially the same and are the Barten-Model compliant.

1-2. Gradation Characteristics of Embodiment

The DICOM does not specify the JND index corresponding to the luminance of less than 0.05 (cd/m^2). In other words, the GSDF specified by the DICOM is not applicable for luminance less than 0.05 (cd/m^2). Therefore, if the luminance of less than 0.05 (cd/m^2) is assigned to the display gradation of the image display device, the gradation characteristic of the image display device will be outside of the GSDF of the DICOM. Thus, in an embodiment, the JND index corresponding to the luminance of less than 0.05 (cd/m^2) is specified using the same Barten Model and the same parameters that were used to calculate the GSDF. To be compatible with the JND indexes of the DICOM standard, the JND indexes corresponding to the luminance of less than 0.05 cd/m^2 are defined and extended using 0 and negative integers that cannot be taken originally. The JND value is also expressed as 0 and negative, and can be a value other than an integer (e.g., a real number). Specifically, the gradation characteristic of the image display device **1** according to the embodiment is configured from the first and second gradation characteristics.

The luminance of the first gradation characteristic is 0.05 (cd/m^2) or more. And the first gradation characteristic complies with the gradation characteristic of the GSDF of the DICOM. In other words, the first gradation characteristic is represented by the JND index already specified by the DICOM and the corresponding luminance for the JND index.

The luminance of the second gradation characteristic is less than 0.05 (cd/m^2). Preferably, the luminance of the second gradation characteristic is more than 0.001 (cd/m^2) but less than 0.05 (cd/m^2). As described above, the GSDF of the DICOM is not applicable for the luminance less than 0.05 (cd/m^2). Therefore, in the embodiment, in order to extend the applicable range of the GSDF from the luminance above 0.05 (cd/m^2) to the luminance less than 0.05 (cd/m^2), the JND index of the second gradation characteristic is obtained based on the Barten-Model. The JND index of the second gradation characteristic is specified as an integer less than 1, which is extended from the JND index of GSDF, which is specified as an integer larger than 1. For this reason, in the embodiment. The JND index of the second gradation characteristic may be referred to as the extended JND index, and the second gradation characteristic may be referred to as the gradation characteristic of the extended GSDF. The method of obtaining the extended JND index is described later.

2. Overall Configuration

This section describes the overall configuration of an image display system **100**, including an image display device **1** according to the embodiment. The image display system **100** of this embodiment has the image display device **1** and an information processing device **2**, as shown in FIG. **1**. The image display device **1** includes an arithmetic processing unit **1**A, a LUT (Look Up Table) **1**B, an image processing unit **1**C, an image display unit **1**D, a memory **1**E, an operation unit **1**F, a control unit **1**G, and a sensor **1**H.

Each of the above components may be realized by software or by hardware. When realized by software, various functions can be realized by the CPU executing the computer program. The program may be stored in built-in memory or a computer-readable non-transitory storage medium. Further, the program stored in the external the memory may be read and realized by so-called cloud computing. When realized by hardware, it can be realized by various circuits such as ASIC, FPGA, or DRP. The present embodiment deals with various information and concepts encompassing the same, which are represented by high and low signal values as a collection of binary bits consisting of 0 or 1, and communication and arithmetic operations can be performed by the above software or hardware manner.

The image display device **1** according to the embodiment can be applied, for example, to an image reading system for medical use or an image diagnosis system for medical use. The image display device **1** according to the embodiment can also be applied, for example, to a diagnostic method using medical images. The image display device **1** acquires the image data from the information processing device **2** and outputs the processed image data to the image display unit **1**D. The information processing device **2** controls the image display device **1** and the sensor **1**H. In addition, the information processing device **2** outputs the image data to the image display unit **1**D for display on the image display device **1**. The sensor **1**H measures the luminance of the image display unit **1**D. In the embodiment, the sensor **1**H is described as being built into the image display device **1**, but it is not limited to this configuration.

3. Detailed Configuration of Image Display Device 1

3-1. Arithmetic Processing Unit 1A

The arithmetic processing unit **1**A reads the program stored in the memory **1**E and executes various arithmetic processes, and is configured with the CPU, for example. The arithmetic processing unit **1**A includes an extended JND difference calculation part **10**, a conversion unit **11**, a target JND value calculation part **12**, a target luminance calculation part **13** and an approximate formula generator **14**. The JND value and JND index described above are used in the arithmetic processing unit **1**A.

As will be explained next, the function of the arithmetic processing unit **1**A is different when the minimum luminance Lmin is less than 0.05 (cd/m^2) and when it is 0.05 (cd/m^2) or more. When the minimum luminance Lmin is less than 0.05 (cd/m^2), the arithmetic processing unit **1**A performs the processing related to the gradation characteristics of both the first and second gradation characteristics. In contrast, when the minimum luminance Lmin is 0.05 (cd/m^2) or more, the arithmetic processing unit **1**A performs the processing related to the gradation characteristic of the first gradation characteristic. In this case, the process is the same as the conventional one. First, the case where the minimum luminance Lmin is less than 0.05 (cd/m^2) is described.

3-1-1. In Case where Minimum Luminance Lmin is Less than 0.05 (Cd/m^2) (Extended JND Difference Calculation Part 10)

The extended JND difference calculation part **10** acquires the various parameters and the minimum luminance Lmin. The various parameters are the parameters of the Barten-Model, such as M_{opt} shown in FIG. **6**A. The various parameters are stored in the memory **1**E. When the operator of the image display device **1** enters the value of the minimum luminance Lmin using the operation unit **1**F, the extended JND difference calculation part **10** can acquire the minimum luminance Lmin.

The extended JND difference calculation part **10** has a function to calculate the temporary minimum luminance Lmin_tmp from the minimum luminance Lmin using a predetermined relationship (the first function). The predetermined relationship is represented by the formula shown in FIG. **6**B, which is based on the Barten-Model.

The extended JND difference calculation part **10** also has a function to calculate the luminance using the formula shown in FIG. **6**B (the second function).

First Function: Calculation of Temporary Minimum Luminance Lmin_Tmp

The formula shown in FIG. **6**B is derived from the contrast sensitivity function shown in FIG. **6**A. q_1 to q_3 are the values shown in FIG. **6**A, and M_{opt} is the optical modulation transfer function, C_{sph} is the main pupil diameter dependent component, d is the pupil diameter, and σ_0 is the standard deviation of the optical LSF (Line Spread Function) for small pupil diameters. This predetermined relationship, given the minimum luminance Lmin, can recursively calculate the corresponding luminance for the JND value that is n (n≥1 and a positive integer) larger than the minimum luminance. The process of recursively calculating the luminance using the predetermined relationship is explained based on FIG. **9**.

In FIG. **9**, L_0 is the minimum luminance. The number of each luminance are given for convenience. In other words, each the luminance number (0-19) in FIG. **9** is different from the JND index (1-19) in the JND index table specified by the DICOM. In FIG. **9**, the minimum luminance L_0 is less than 0.05 (cd/m^2), which is not specified by the JND index table of the DICOM.

Given the minimum luminance L_0, the luminance L_1 can be calculated by using the formula shown in FIG. **6**B. After this recursive calculation is repeated, the value exceeds 0.05 (cd/m^2) for the first time at L_{19}. In the embodiment, the luminance that exceeds 0.050 (cd/m^2) for the first time is defined as the temporary minimum luminance Lmin_tmp. In other words, the temporary minimum luminance Lmin_tmp is the luminance that is above the predetermined luminance (0.05 in the case of the embodiment) for the first time when repeated recursively calculating each luminance using the predetermined relationship. Therefore, in FIG. **9**, L_{19} is the temporary minimum luminance Lmin_tmp.

Second Function: Calculation of Extended JND Difference Jext

Each luminance shown in FIG. **9** is the corresponding luminance for the extended JND. The number of the extended JND is counted in order from the smallest luminance in each luminance. In other words, the number of the JND for the minimum luminance L_0 is assigned **0**, and the number of the JND for the luminance L_1 is assigned 1. The luminance after the luminance L_2 will be assigned sequentially. Here, the extended JND difference Jext corresponds to the number of JNDs whose luminance is less than 0.05 (cd/m^2), as shown in FIG. **9**. In other words, the extended JND difference Jext corresponds to the number of JNDs that are smaller than the temporary minimum luminance Lmin_tmp. In FIG. **9**, there are a total of 19 values (L_0 to L_{18}) for which the luminance is smaller than L_{19}, which corresponds to the temporary minimum luminance Lmin_tmp. Therefore, in FIG. **9**, the extended JND difference Jext is 19.

Second Function: Calculation of Extended JND Index

The extended JND difference calculation part **10** can also acquire the extended JND index, as explained next.

In FIG. **9**, the temporary minimum JND value Jmin_tmp was different from the luminance (=0.05 (cd/m^2)) of the JND index=1. Here, the extended JND difference calculation part **10** defines the minimum luminance L_0 (starting luminance) so that the temporary minimum JND value Jmin_tmp corresponds to the luminance of the JND index=1.

Specifically, as shown in FIG. **10**, the extended JND difference calculation part **10** defines the minimum luminance L_0 to be 0.0010 (cd/m^2). Then, the extended JND difference calculation part **10** performs the calculations described in the second function in turn and calculates the luminance L_0 to the luminance L_{19}. Here, when the extended JND difference calculation part **10** defines the minimum luminance L_0 to be 0.0010 (cd/m^2), the L_{19} corresponding to the temporary minimum JND value Jmin_tmp is 0.05 (cd/m^2), which is equal to the luminance of the JND index=1. Therefore, L_0 to L_{18} can be specified as the luminance corresponding to the JND index of less than 1. In other words, L_{18} is the luminance corresponding to JND index=0, L_{17} is the luminance corresponding to JND index=−1, and . . . L_0 is the luminance corresponding to JND index=−18. From the above, the extended JND difference calculation part **10** can acquire the JND index less than 1, i. e., the extended JND index, and the corresponding luminance

Conversion Unit **11**

The conversion unit **11** acquires the temporary minimum luminance Lmin_tmp and the maximum luminance Lmax. As shown FIG. **2**, the conversion unit **11** acquires the temporary minimum luminance Lmin_tmp from the extended JND difference calculation part **10**. When the operator of the image display device **1** enters the value of the maximum luminance Lmax using the operation unit **1**F, the conversion unit **11** acquires the maximum luminance Lmax. Since the temporary minimum luminance Lmin_tmp and the maximum luminance Lmax are both larger than 0.05 (cd/m^2), formula 3 specified by the DICOM can be applied. In other words, the conversion unit **11** has the function to convert the luminance to the JND value based on formula 3 specified by the DICOM, as shown in FIG. **7**A. Specifically, as shown in FIG. **2**, the conversion unit **11** converts the temporary minimum luminance Lmin_tmp calculated by the extended JND difference calculation part **10** to the temporary minimum JND value Jmin_tmp. The conversion unit **11** converts the maximum luminance Lmax to the maximum JND value Jmax.

Target JND Value Calculation Part **12**

The target JND value calculation part **12** acquires the temporary minimum JND value Jmin_tmp and the maximum JND value Jmax from the conversion unit **11**. Also, the target JND value calculation part **12** acquires the extended JND difference Jext from the extended JND difference calculation part **10**. The target JND value calculation part **12** calculates the target JND value Jm_target for each gradation based on the maximum JND value Jmax, the extended JND difference Jext, the temporary minimum JND value Jmin_tmp, and the number of gradations. In the embodiment, it is described that there are gradations from 0 to 255, but it is not limited to this. The process of calculating the target JND value Jm_target is described below.

First, the target JND value calculation part **12** calculates ΔJND based on formula 5 shown in FIG. **8**A. ΔJND is the difference in the JND values between adjacent gradations. The difference in the JND values between adjacent gradations is the same for all adjacent gradations. In the embodiment, the maximum luminance Lmax is set to 1000 (cd/m^2). In this case, the maximum JND value is 810.49. As shown in FIG. **9**, the minimum luminance is set to 0.0015 (cd/m^2). At this time, the L_{19} corresponding to the temporary minimum luminance, calculated by recursive calculation, is 0.05268 (cd/m^2). Therefore, the temporary minimum JND value Jmin_tmp is 1.62 (cd/m^2). Also, as described above, Jext is 19. Thus, as shown in FIG. **8***a*, ΔJND is 3.246.

Next, the target JND value calculation part **12** calculates the target JND value Jm_target for each gradation based on formula 6 shown in FIG. **8**B. In formula 6, m is an integer between 0 and 255. The relationship between each gradation and the target JND value is shown in FIG. **11**. In FIG. **11**, the six target JND values within the dashed rectangle shown in FIG. **11** have values less than 1 and correspond to the extended JND index (−19 to 0).

Target Luminance Calculation Part **13**

The target luminance calculation part **13** calculates the target luminance of the first and second gradation characteristics (see FIG. **12**) based on the target JND value for each gradation. In the range where the target JND value is larger than 1 (the range of the first gradation characteristic), the target luminance calculation part **13** converts the target JND value to the target luminance based on formula 4 shown in FIG. **7**B. In other words, the first gradation characteristic complies with the gradation characteristic of the GSDF of the DICOM. That is, the first gradation characteristic is defined to satisfy the relationship between the JND value (the JND index) of 1 or more and the corresponding luminance for this (see the solid line in FIG. **12**).

Formula 4 cannot be applied when the target JND value is less than 1. For this reason, in the range where the target JND value is less than 1 (the range of the second gradation characteristic), the target luminance calculation part **13** converts the target JND value to the target luminance based on the approximation formula Lapprox described below.

The extended JND index acquired by the extended JND difference calculation part **10** has integer JND values, but the approximation formula Lapprox can be applied to non-integer JND values. In other words, the extended JND index and the corresponding luminance for this and the approximation formula Lapprox are essentially the same gradation characteristic, although there is a difference in whether the applicable JND values include non-integers or not. That is, the approximate formula Lapprox is a formula that expresses the relationship between the JND value (the JND index) of less than 1 and the corresponding luminance for this. Thus, in the embodiment, the approximation formula Lapprox (see dashed line in FIG. **12**) is a formula that defines the second gradation characteristic. Then, the second gradation characteristic is defined so that it satisfies the relationship between the JND value (the JND index) of less than 1 and the corresponding luminance for this (the dashed approximate formula Lapprox in FIG. **12**).

As described above, the first gradation characteristic (the gradation characteristic having the luminance of 0.05 (cd/m^2) or more) complies with the gradation characteristic of the GSDF of the DICOM, it satisfies the relationship between the JND value and the corresponding luminance for this. The second gradation characteristic (the gradation characteristic having a luminance less than 0.05 (cd/m^2)) also satisfies the relationship between the JND value and the corresponding luminance for this. Therefore, in the embodiment, the gradation characteristic compatible with the GSDF is extended to the luminance region of less than 0.05 (cd/m^2).

Approximate Formula Generator **14**

Formula 4 is a formula that converts the JND value to luminance, but it cannot be applied when the JND value is less than 1. The extended JND index is an integer, but the target JND value for each gradation is not necessarily an integer. Based on these, the approximate formula generator **14** generates a formula that can properly convert the JND value to the luminance even if the JND value is less than 1 and the JND value is not an integer.

Here, the existing JND value corresponding to the GSDF and the corresponding luminance for this are referred to as the value V1 for the first gradation characteristic (see FIG. **2**). Also, the extended JND value and the corresponding luminance for this are referred to as the value V2 for the second gradation characteristic. The approximate formula generator **14** generates the approximate formula Lapprox based on the values V1 and V2 for the first and second gradation characteristic. The type of the approximation formula Laprox is assumed to be a fifth-order function in the embodiment, but it is not limited to this and can be changed as needed.

The approximate formula generator **14** generates the approximate formula Lapprox using the value V1 for the first gradation characteristic in addition to the value V2 for the second gradation characteristic (see FIG. **12**) so that the approximate formula Lapprox to be smoothly connected to the GSDF-based curve (the curve in the range where the JND index is larger than or equal to 1).

The value V1 for the first gradation characteristic may have the same number of JND indexes as the extended JND index, for example. In other words, in the embodiment, the value V2 for the second gradation characteristic has the JND index of −18 to 0 and the corresponding luminance for this, so the value V1 for the first gradation characteristic should have the JND index of 1 to 19 and the corresponding luminance for this. The approximate formula generator **14** substitutes the values V1 and V2 for the first and second gradation characteristics into the approximate formula Lapprox and performs regression analysis to acquire the coefficients a to e and the intercept f of the approximate formula Lapprox. This allows the approximate formula generator **14** to generate the approximate formula Lapprox.

3-1-2. In Case where Minimum Luminance Lmin is 0.05 (Cd/m^2) or More Conversion Unit **11**

As shown in FIG. **3**, the conversion unit **11** acquires the minimum luminance Lmin and the maximum luminance Lmax. The operator of the image display device **1** inputs the values of the minimum luminance Lmin and the maximum luminance Lmax using the operation unit **1**F, and the conversion unit **11** acquires the minimum luminance Lmin and the maximum luminance Lmax. The conversion unit **11** converts the minimum luminance Lmin to the minimum JND value Jmin, and the maximum luminance Lmax to the maximum JND value Jmax.

Target JND Value Calculation Part **12**

The target JND value calculation part **12** calculates the target JND value Jm_target in a known manner, as described below. As shown in FIG. **3**, the target JND value calculation part **12** acquires the minimum JND value Jmin and the maximum JND value Jmax from the conversion unit **11**. The target JND value calculation part **12** calculates the target JND value Jm_target for each gradation based on the minimum JND value Jmin, the maximum JND value Jmax, and the number of gradations. Specifically, the target JND value calculation part **12** calculates the target JND value Jm_target based on formula 7 shown in FIG. **8**C.

Target Luminance Calculation Part **13**

The target luminance calculation part **13** calculates the target luminance of the first gradation characteristic based on the target JND value for each gradation. The target luminance calculation part **13** converts the target JND value to the target luminance based on formula 4 shown in FIG. **7**B.

3-2. LUT **1**B

LUT **1**B has LUT data. The LUT data is configured as a table of output data (conversion table) that is associated with the input data. The input data corresponds to the image data to be acquired from the information processing device **2**, and the image data converted through the LUT **1**B is input to the image processing unit **1**C. As the image display device **1** includes LUT **1**B, it is easy to change the mapping of the LUT data. The number of gradations that can be represented in the LUT data (bit depth) is specific to the image display device **1**, and generally there are more bits in the output data than in the input data.

As the process of performing the calibration shown in FIG. **4** below, the LUT data of the image display device **1** is set to default values. Then, the control unit **1**G adjusts the luminance of the white so that the luminance of the image display unit **1**D is above the maximum luminance value, which is generally the target. The image used for the measurement may be the image data from the information processing device **2**, or it may be the specified image data stored in advance by the image display device **1**. The sensor **1**H measures the luminance of the image display unit **1**D at the specified gradation value (measurement gradation value). Here, in the image display device **1**, the measured gradation value and the corresponding measured luminance are mapped to the LUT data of the basic characteristics of the image display device **1**. Then, when the target luminance calculation part **13** acquires the target luminance of each gradation, the suitable LUT data is selected from the LUT data of the basic characteristics to make the target luminance of each graduation. In the area where the luminance is 0.05 (cd/m^2) or more, the target luminance acquired by the target luminance calculation part **13** complies with the GSDF. Also, in the area where the luminance is less than 0.05 (cd/m^2), the target luminance acquired by the target luminance calculation part **13** complies with the extended GSDF. Therefore, LUT **1**B will be selected as the LUT data corresponding to the GSDF or the extended GSDF. The luminance of the LUT data between the measured gradation values can be acquired by interpolation.

3-3. Image Processing Unit **1**C and Image Display Unit **1**D

The image processing unit **1**C performs image processing based on the LUT data (output), and the image display unit **1**D displays the processed data. The image display unit **1**D displays image data (including still images and videos) as images. The image display unit **1**D can be configured with a liquid crystal display and an organic EL display, for example.

3-4. Memory **1**E

The memory **1**E stores various data and programs. The memory **1**E stores, for example, the Barten-Model parameters, formulas 1 to 7 shown in FIG. **6**A to **8**C, and so on. Also, the image data for the measurement of the sensor **1**H is stored in the memory **1**E.

3-5. Operation Unit **1**F

The image display device **1** is operated by the operation unit **1**F, which can be configured with buttons, a touch panel, and a voice input device, for example. In the embodiment, the minimum luminance Lmin and the maximum luminance Lmax are input through the application that the information processing device **2** has, but may be input using the operation unit **1**F.

3-6. Control Unit **1**G

The control unit **1**G controls (adjusts) the luminance of the image displayed on the image display unit **1**D when performing the calibration described in the flowchart below.

3. Flowchart

3-1. Overall Configuration

An example of a control flowchart of the image display system **100** is described based on FIG. **4**. The flowchart in FIG. **4** shows the basic process of calibration, which includes the luminance adjustment of the white screen (step S**3**), and the LUT adjustment to select the suitable LUT data to make the display luminance of each gradation the target luminance (step S**6**).

The operator inputs the minimum luminance Lmin and the maximum luminance Lmax via the information processing device **2** application, and the image display device **1** acquires the minimum luminance Lmin and the maximum luminance Lmax (step S**1**). The minimum luminance Lmin can also be the value measured by the sensor **1**H. The arithmetic processing unit **1**A writes the default value of the LUT data stored in advance in the memory **1**E to the LUT (step S**2**). The control unit **1**G makes the white screen data appear on the image display unit **1**D, the sensor **1**H measures the luminance of the image display unit **1**D, and the control unit **1**G adjusts the luminance of the image display unit **1**D (step S**3**). The control unit **1**G repeats the change of the luminance of the image display unit **1**D and the measurement of luminance by the sensor **1**H until it is within the predetermined range of the luminance.

The image data of the specified plurality of gradations stored in the memory **1**E is displayed on the image display unit **1**D, and the sensor **1**H measures the luminance of the image display unit **1**D (step S**4**). The measured luminance of the unmeasured gradations can be acquired by interpolation.

The arithmetic processing unit **1**A acquires the target luminance (step S**5**). The details of step S**5** are described in "3-2. TARGET LUMINANCE CALCULATION FLOW". Then, the arithmetic processing unit **1**A selects the suitable LUT data to make the target luminance based on the measured luminance acquired in step S**4** and the target luminance acquired in step S**5** (step S**6**).

3.2 Target Luminance Calculation Flow

An example of a flowchart for acquiring the target luminance is described based on FIG. **5**.

Step S**11**

The arithmetic processing unit **1**A determines whether the minimum luminance Lmin is less than 0.05 (cd/m^2). If the minimum luminance Lmin is less than 0.05 (cd/m^2), move to step S**12**, if the minimum luminance Lmin is larger than 0.05 (cd/m^2), move to step S**19**.

In the case of moving from step S**11** to step S**12**, the minimum luminance Lmin is less than 0.05 (cd/m^2), so the image display device **1** needs to display the image data while taking into account not only the first gradation characteristic but also the second gradation characteristic. Therefore, the arithmetic processing unit **1**A performs the steps described below and acquires the extended JND value.

On the other hand, in the case of moving from step S**11** to step S**19**, the minimum luminance Lmin is 0.05 (cd/m^2) or more, so the image display device **1** can display the image data while taking into account the first gradation characteristic (GSDF). In this case, the target luminance can be acquired in the same manner as the existing method.

Step S**12** to Step S**14**: Acquisition of Lmin_Tmp and Jext by Recursive Calculations

The extended JND difference calculation part **10** substitutes the minimum luminance L_0 corresponding to the minimum extended JND index into the formula shown in FIG. **6**B, and calculates the luminance L_1 corresponding to the next extended JND index (step S**12**). In the embodiment, the minimum luminance L_0 is 0.00150 and the luminance L_1 is 0.00246. The extended JND difference calculation part **10** determines whether the luminance L_1 corresponding to the next extended JND index is 0.05 (cd/m^2) or more (step S**13**). Since the luminance L_1 is not larger than 0.05 (cd/m^2), the calculation is repeated in Step S**12**. Step S**12** and step S**13** are repeated until the luminance L_{19}, which is 0.05268 (cd/m^2), is calculated. Then, the extended JND difference calculation part **10** acquires the temporary minimum luminance Lmin_tmp (=L_{19}) and the extended JND difference Jext as a result of the repeated calculations in step S**12** and step S**13** (step S**14**).

Step S**15**: Converting Luminance to JND Values

The conversion unit **11** converts the maximum luminance Lmax to the maximum JND value Jmax and the temporary minimum luminance Lmin_tmp to the temporary minimum JND value Jmin_tmp based on formula 3 shown in FIG. **7**A. In the embodiment, the maximum luminance Lmax is 1000 (cd/m^2), so the maximum JND value Jmax is 810.49, and the temporary minimum luminance Lmin_tmp is 0.05268 (cd/m^2), so the temporary minimum JND value Jmin_tmp is 1.62.

Step S**16** and Step S**17**: Calculation of ΔJND and Target JND Value

The target JND value calculation part **12** calculates ΔJND using the maximum JND value Jmax, the extended JND difference Jext, the temporary minimum JND value Jmin_tmp, and the number of gradations based on formula 5 shown in FIG. **8**A (step S**16**). In the embodiment, the maximum JND value Jmax is 810.49, the temporary minimum JND value Jmin_tmp is 1.62, and the extended JND difference Jext is 19. Therefore, in the embodiment, ΔJND is 3.246. Next, the target JND value calculation part **12** acquires the target JND value for each gradation based on formula 6 shown in FIG. **8**B (step S**17**).

Step S**18**: Generation of Approximation Formula Laprox and Calculation of Target Luminance

The approximate formula generator **14** generates the approximate formula Lapprox based on the values V1 and V2 for the first and second gradation characteristics. The value V2 for the second gradation characteristic is acquired in the recursive calculation of step S**12** to step S**14**. Also, the approximate formula generator **14** can acquire the value V1 for the first gradation characteristic from the memory **1**E.

The target luminance calculation part **13** calculates the target luminance of the first and second gradation characteristics based on the target JND value for each gradation. If the target JND value is larger than or equal to 1, the target luminance calculation part **13** converts the target JND value to the target luminance based on formula 4 shown in FIG. **7**B. If the target JND value is less than 1, the target luminance calculation part **13** converts the target JND value to the target luminance based on the approximation formula Lapprox.

Step S**19** to Step S**21**: Calculation of Target Luminance Using Existing Methods

The conversion unit **11** converts the maximum luminance Lmax to the maximum JND value Jmax and the minimum luminance Lmin to the minimum JND value Jmin based on formula 3 shown in FIG. **7**A (Step S**19**).

The target JND value calculation part **12** calculates the target JND value Jm_target for each gradation using the maximum JND value Jmax, the minimum JND value Jmin, and the number of gradations based on formula 7 shown in FIG. **8**C (step S**20**).

The target luminance calculation part **13** converts the target JND value for each gradation to the target luminance based on formula 4 shown in FIG. **7**B.

4. Modification

As shown in FIG. **13**, in the image display system **100**, the arithmetic processing unit **1**A may be included in the information processing device **2**. In other words, the information processing device **2** may acquire the relationship between the JND value and the corresponding luminance described in the embodiment in advance, and the image display device **1** may acquire the relationship from the information processing device **2**.

Also, in this modification, the sensor **1**H is not built into the image display device **1**, but is provided outside the image display device **1**. In this modification, the information processing device **2** controls the sensor **1**H and receives the detection results of the sensor **1**H. In addition, the information processing device **2** stores the image data of the specified plurality of gradations. The information processing device **2** outputs the image data of each gradation and the luminance measured by the sensor **1**H to the image display device **1**, and the calibration described in FIG. **4** is performed. Even with this modification, the same effect as the embodiment can be realized.

5. Other Embodiments

The image display device **1** according to the embodiment may be the image display device that can display color images. For example, the image display device **1** should be able to display an image with the first and second gradation characteristics when displaying a grayscale image.

REFERENCE SIGNS LIST

1: image display device
1A: arithmetic processing unit
1C: image processing unit
1D: image display unit
1E: memory
1F: operation unit
1G: control unit
1H: sensor
2: information processing device
10: extended JND difference calculation part
11: conversion unit
12: target JND value calculation part
13: target luminance calculation part
14: approximate formula generator
100: image display system
Jext: extended JND difference
Jm_target: target JND value
Jmax: maximum JND value
Jmin: minimum JND value
Jmin_tmp: temporary minimum JND value
Lmax: maximum luminance
Lmin: minimum luminance
Lmin_tmp: temporary minimum luminance

The invention claimed is:

1. An image display device for medical use configured to display image data comprising:

an image display unit; and

an image processing unit, wherein

the image processing unit is configured to display the image data on the image display unit based on first and second gradation characteristics,

the first gradation characteristic has a luminance of 0.05 cd/m^2 or more,

the second gradation characteristic has a luminance of less than 0.05 cd/m^2,

the first gradation characteristic complies with (Grayscale Standard Display Function (GSDF) gradation characteristic of a Digital Imaging and Communications in Medicine (DICOM) standard,

the first gradation characteristic is defined to satisfy a relationship between a Just Noticeable Difference (JND) value complying with GSDF and a corresponding luminance,

the second gradation characteristic is a gradation characteristic that extends, based on a Barten-Model, over an applicable range of GSDF from a first luminance above 0.05 cd/m^2 to a second luminance less than 0.05 cd/m^2, and

the second gradation characteristic is defined to satisfy a relationship between an extended JND value complying with extended GSDF and a corresponding luminance.

2. The image display device of claim **1**, wherein

the relationship in the second gradation characteristic corresponds to a relationship between a target JND value and a corresponding target luminance,

the target luminance corresponds to the corresponding luminance,

the target JND value is calculated based on a maximum JND value, an extended JND difference, a temporary minimum JND value, and a number of gradations, wherein the number of gradations is a predetermined value in the image display device,

the maximum JND value corresponds to a maximum luminance of the image display unit,

the temporary minimum JND value corresponds to a temporary minimum luminance, and the temporary minimum JND value is calculated from a minimum luminance using a predetermined relationship,

the minimum luminance is less than 0.05 cd/m^2,

when the minimum luminance is given, the predetermined relationship is capable of recursively calculating a luminance corresponding to a JND value that is larger than a minimum JND value corresponding to the minimum luminance by at least a value n, wherein n≥1, the temporary minimum luminance is a luminance that becomes larger than a predetermined luminance for the first time when a recursive calculation of each luminance using the predetermined relationship is repeated, and

the extended JND difference corresponds to a number of luminance which is used to calculate the temporary minimum luminance, said number of luminance being smaller than the temporary minimum luminance.

3. The image display device of claim **1** further comprising:

an arithmetic processing unit, wherein

the arithmetic processing unit includes an extended JND difference calculation part, a target JND value calculation part, and a target luminance calculation part,

the extended JND difference calculation part calculates a temporary minimum luminance from a minimum luminance using a predetermined relationship and calculates an extended JND difference,

when the minimum luminance is given, the predetermined relationship is capable of recursively calculating a luminance corresponding to a JND value that is larger than a minimum JND value corresponding to the minimum luminance by at least a value n, wherein n≥1,

the temporary minimum luminance is a luminance that becomes larger than a predetermined luminance for the first time when a recursive calculation of each luminance using the predetermined relationship is repeated,

the minimum luminance is less than 0.05 cd/m^2,

the extended JND difference corresponds to a number of luminance which is used to calculate the temporary minimum luminance, said number of luminance being smaller than the temporary minimum luminance,

the target JND value calculation part calculates a target JND value for each gradation based on a maximum JND value corresponding to a maximum luminance of the image display unit, the extended JND difference, a temporary minimum JND value corresponding to the temporary minimum luminance, and a number of gradations, wherein the number of gradations is a predetermined value in the image display device,

the target luminance calculation part calculates a target luminance based on the target JND value,

the target JND value corresponds to the JND value of the first and second gradation characteristics, and

the target luminance corresponds to the corresponding luminance of the first and second gradation characteristics.

4. The image display device of claim **1**, wherein

the JND value for the first gradation characteristic is assigned a real number larger than or equal to 1, and

the JND value for the second gradation characteristic is assigned a real number less than 1.

5. The image display device of claim **1**, wherein

a JND index for the first gradation characteristic is assigned an integer larger than or equal to 1, and

a JND index for the second gradation characteristic is assigned an integer less than 1.

6. The image display device of claim **5**, wherein

the JND index for the second gradation characteristic is assigned a negative integer.

7. An image display system for medical use configured to display image data comprising:

an image display unit; and

an image processing unit, wherein

the image processing unit is configured to display the image data on the image display unit based on first and second gradation characteristics,

the first gradation characteristic has a luminance of 0.05 cd/m^2 or more,

the second gradation characteristic has a luminance of less than 0.05 cd/m^2,

the first gradation characteristic complies with (Grayscale Standard Display Function (GSDF) gradation characteristic of a Digital Imaging and Communications in Medicine (DICOM) standard,

the first gradation characteristic is defined to satisfy a relationship between a Just Noticeable Difference (JND) value complying with GSDF and a corresponding luminance,

the second gradation characteristic is a gradation characteristic that extends, based on a Barten-Model, over an applicable range of GSDF from a first luminance above 0.05 cd/m^2 to a second luminance less than 0.05 cd/m^2, and

the second gradation characteristic is defined to satisfy a relationship between an extended JND value complying with extended GSDF and a corresponding luminance.

8. The image display system of claim **7**, wherein

the relationship in the second gradation characteristic corresponds to a relationship between a target JND value and a corresponding target luminance,

the target luminance corresponds to the corresponding luminance,

the target JND value is calculated based on a maximum JND value, an extended JND difference, a temporary minimum JND value, and a number of gradations, wherein the number of gradations is a predetermined value in the image display device,

the maximum JND value corresponds to a maximum luminance of the image display unit,

the temporary minimum JND value corresponds to a temporary minimum luminance, and the temporary minimum JND value is calculated from a minimum luminance using a predetermined relationship,

the minimum luminance is less than 0.05 cd/m^2,

when the minimum luminance is given, the predetermined relationship is capable of recursively calculating a luminance corresponding to a JND value that is larger than a minimum JND value corresponding to the minimum luminance by at least a value n, wherein n≥1,

the temporary minimum luminance is a luminance that becomes larger than a predetermined luminance for the first time when a recursive calculation of each luminance using the predetermined relationship is repeated, and

the extended JND difference corresponds to a number of luminance which is used to calculate the temporary minimum luminance, said number of luminance being smaller than the temporary minimum luminance.

9. The image display system of claim **7** further comprising:

an arithmetic processing unit, wherein

the arithmetic processing unit includes an extended JND difference calculation part, a target JND value calculation part, and a target luminance calculation part, the extended JND difference calculation part calculates a temporary minimum luminance from a minimum luminance using a predetermined relationship and calculates an extended JND difference,

when the minimum luminance is given, the predetermined relationship is capable of recursively calculating a luminance corresponding to a JND value that is larger than a minimum JND value corresponding to the minimum luminance by at least a value n, wherein n≥1,

the temporary minimum luminance is a luminance that becomes larger than a predetermined luminance for the first time when a recursive calculation of each luminance using the predetermined relationship is repeated,

the minimum luminance is less than 0.05 cd/m^2,

the extended JND difference corresponds to a number of luminance which is used to calculate the temporary minimum luminance, said number of luminance being smaller than the temporary minimum luminance,

the target JND value calculation part calculates a target JND value for each gradation based on a maximum JND value corresponding to a maximum luminance of the image display unit, the extended JND difference, a temporary minimum JND value corresponding to the temporary minimum luminance, and a number of gradations, wherein the number of gradations is a predetermined value in the image display device,

the target luminance calculation part calculates a target luminance based on the target JND value,

the target JND value corresponds to the JND value of the first and second gradation characteristics, and

the target luminance corresponds to the corresponding luminance of the first and second gradation characteristics.

10. The image display system of claim **7**, wherein

the JND value for the first gradation characteristic is assigned a real number larger than or equal to 1, and

the JND value for the second gradation characteristic is assigned a real number less than 1.

11. The image display system of claim **7**, wherein

a JND index for the first gradation characteristic is assigned an integer larger than or equal to 1, and

a JND index for the second gradation characteristic is assigned an integer less than 1.

12. The image display system of claim **11**, wherein

the JND index for the second gradation characteristic is assigned a negative integer.

13. An image display method for medical use and displaying image data comprising:

a display step of displaying the image data on an image display unit based on first and second gradation characteristics, wherein

the first gradation characteristic has a luminance of 0.05 cd/m^2 or more,

the second gradation characteristic has a luminance of less than 0.05 cd/m^2,

the first gradation characteristic complies with (Grayscale Standard Display Function (GSDF) gradation characteristic of a Digital Imaging and Communications in Medicine (DICOM) standard,

the first gradation characteristic is defined to satisfy a relationship between a Just Noticeable Difference (JND) value complying with GSDF and a corresponding luminance,

the second gradation characteristic is a gradation characteristic that extends, based on a Barten-Model, over an applicable range of GSDF from a first luminance above 0.05 cd/m^2 to a second luminance less than 0.05 cd/m^2, and

the second gradation characteristic is defined to satisfy a relationship between an extended JND value complying with extended GSDF and a corresponding luminance.

14. A non-transitory computer readable medium that stores a computer program causing a computer to execute an image display method for medical use and displaying image data comprising:

a display step of displaying the image data on an image display unit based on first and second gradation characteristics, wherein

the first gradation characteristic has a luminance of 0.05 cd/m^2 or more,

the second gradation characteristic has a luminance of less than 0.05,

the first gradation characteristic complies with (Grayscale Standard Display Function (GSDF) gradation characteristic of a Digital Imaging and Communications in Medicine (DICOM) standard,

the first gradation characteristic is defined to satisfy a relationship between a Just Noticeable Difference (JND) value complying with GSDF and a corresponding luminance,

the second gradation characteristic is a gradation characteristic that extends, based on a Barten-Model, over an applicable range of GSDF from a first luminance above 0.05 cd/m^2 to a second luminance less than 0.05 cd/m^2, and

the second gradation characteristic is defined to satisfy a relationship between an extended JND value complying with extended GSDF and a corresponding luminance.

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